Utilization of Re-Processed Anaerobically Digested Fiber from Dairy Manure as a Container Media Substrate

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Abstract

The solid fraction (fiber) from the effluent of the anaerobic digestion of dairy manure by plug flow technology yields material that has consistent physical properties (total porosity, air filled porosity at saturation, and water holding capacity) to perform satisfactorily as a plant growth media substrate. Since September 2002, 28 greenhouse trials have been conducted using anaerobic digester fiber as a 1:1 replacement for peat moss in container media. Plants grown in unamended fiber have robust root systems, but chlorotic shoots which initial trials indicated is due to unavailability of Fe & Mn. Various methods were used to increase availability of Fe & Mn by acidification and/or supplementation. A simple post digestion acidification treatment process has been developed to produce plants with shoot fresh and dry weight, size, and "greenness" equal to or better than peat moss based media, but which have a stunted root system. In subsequent trials, root digital images were analyzed using software to find differences in root development between treatments. The addition of a second post digestion amendment has produced plants that have large root systems and large, green shoots equal to or better than peat moss based media for a number of common greenhouse crops.

INTRODUCTION

The requirements for plant growth media, including physical, chemical, and other properties are well established (Boertje, 1983; Goh and Haynes, 1977; Raviv et al., 1986).

Nutrient availability is influenced by media pH. Some plant micronutrients, such as Mn, may become unavailable as the pH rises over neutral (pH=7.0) (Hausenbuiller, 1972). Elemental sulfur (S^0) must be oxidized to SO_4 and H^+ and increases soil EC and decreases pH following application to soil (Slaton et al., 2001). The appropriate rate of S^0 added to composted yard waste to be used as a container substrate derived from the equation, 144.5 g $S^0 \times 0.7$ pH unit^{-1} reduction $\times$ m^{-3} (0.25 lbs yd^{-3}) (Beeson, 1996). While pea plants are very sensitive to salinity, pea plants grown in sulphate salinized media adjusted fully to the change in external osmotic potential (Hasson-Porath et al., 1972).

Earlier work using anaerobically digested cow manure as a growth medium substrate (Raviv et al., 1983) showed that washed digested slurry could be suitable. Composted, sieved, and leached effluent of thermophilic digestion of slaughterhouse waste produced a fibrous, peat like material that possessed higher nutrient levels than peat (Marchaim et al., 1991). This paper investigates methods to treat anaerobic digester fiber to be a successful 1:1 replacement for peat moss in container media.

MATERIALS AND METHODS

Samples of fiber, the solid fraction of the effluent from plug flow anaerobic digesters (DF), were obtained from various digesters operating on dairy farms located in Illinois, Wisconsin, Oregon, and Washington from 2002 to 2006. All fiber, growth media, and plant tissue samples were analyzed by the Soil and Plant Laboratory, Santa Clara, California, USA for chemical, nutrient, and physical properties. Some pH and EC data was collected during plant growth trials using a Hanna Instruments pH meter and Spectrum Industries PET 2000 EC Meter.

Experiments with Unmodified DF

Petunia Grandiflora: Single Ultra Violet plugs size 512 were randomized and transplanted into 10.16 cm pots in five media treatments (r=4, n=25). 1) 60% peat, 25% compost (sterilized greenhouse cull plant waste), 15% pumice (P); 2) 85% peat moss and 15% P; 3) 85% DF and 15% P; 4) 60% DF, 25% composted cull plants, 15% P; 5) 40% DF, 40% peat moss and 20% P using DF from a dairy in New York State. All media had dolomite lime ($CaMg(CO_3)_2$) incorporated pre-plant at a rate of 0.59 kg/m^3. Plants were grown at a large commercial greenhouse in Washington State and fertigated daily with a mixture of 20-10-20 and 15-0-15 at 150 ppm N. Plants were harvested 28 days after planting. Plant height (from soil surface to the base of the sepals on the longest flower stalk), number of visible buds and open flowers, greenness of the leaves using a Minolta SPAD-502 leaf chlorophyll meter (Markwell et al., 1995) (average of three readings taken from the 2^{nd} leaf set from the top of the tallest branch), fresh and dry weight of the entire plant cut at soil surface were measured.

pH Adjustment

Dried DF samples (50 ml or 5.5 g) were mixed with 45.0, 89.1, or 133.6 mg of 90% sulfur (S^0) and pH measured weekly over 20 weeks. Initially DF and deionized water was mixed 1:1 on a volume basis and shaken for one hour and allowed to settle before measuring pH. After each pH measurement, the fiber sample was air dried to field capacity (45%), placed in a beaker, stirred, covered with parafilm with 5 pin holes in the center and incubated at 25°C. Starting week 2, DF was mixed with 0.01 M $CaCl_2$ instead of deionized water to take into account the high EC of the material.

Experiments with Mn and Fe Supplements

Petunia Dreams plugs, size 512, were transplanted into 10.16 cm pots in six media treatments and grown in a commercial greenhouse. Treatments (r=4, n=18) included: 1) 80% DF, 20% P, with $MnSO_4$; 2) 80% DF, 20% P with $FeSO_4$; 3) 40% DF, 40% peat moss and 20% P with $MnSO_4$; 4) 40% DF, 40% peat moss and 20% P, with $FeSO_4$; 5) 80% peat moss and 20% P, $MnSO_4$; and 6) 80% peat moss and 20% P, with $FeSO_4$. At planting, pots were treated with 100 ml of 204 ppm of $FeSO_4$ or 95 ppm of $MnSO_4$. Plants were watered as needed and fertilized every third day with 200 ppm N solution using a mixture of soluble 20-10-20. Plants were harvested after 33 days. Plant growth was evaluated as described above.

Experiments with S^0 Treated DF

Petunia Ultra Red & Petunia Ultra Blue (flower color split equally among treatments) plugs size 512, were randomized and grown at the Washington State University research station in Mount Vernon, Washington in 72 cell inserts for standard 1020 flats Treatments (r=4, n=18) included: 1) 70% peat moss, 30% P with 1.78 kg/m^3 dolomite lime (DL) ($CaMg(CO_3)_2$) and 0.89 kg/m^3 limestone flour (LF) ($CaCO_3$); 2-5) 70% DF, 30% P, with no S^0, 0.89 kg/m^3, 1.78 kg/m^3, or 2.67 kg/m^3 S^0. All supplements were incorporated one day pre-plant. Plants were fertigated daily with 125 ppm nitrogen using a 20-20-20 fertilizer. Plants were harvested after 33 days. Chemical analyses of media were conducted at planting and harvest for all treatments. Plant growth was evaluated as described above.

Experiments with S^0 and $CaSO_4$ Supplemented DF

Unrecorded observations suggested that S^0 treated DF did not support adequate root development. Plug *Petunia* Midnight Madness, size 512, were randomized and grown at the Washington State University research station in Mount Vernon, Washington in 500 ml inserts for standard 1020 flats, with five media treatments (r=4, n=18): 1) 80% peat moss, 20% P with 1.78 kg/m^3 DL and 0.89 kg/m^3 LF; 2) 70% DF, 30% P; 3) 70% DF, 30% P with 0.89 kg/m^3 S^0; 4) 70% DF, 30% P with 0.89 kg/m^3 S^0 and 4.15 kg/m^3 gypsum (G) ($CaSO_4 \cdot 2H_2O$); 5) 70% DF, 30% P with 0.89 kg/m3 S^0, 4.15 kg/m^3 G, and

0.89 kg/m^3 LF. All supplements were incorporated one day pre-plant. Plants were fertigated daily with 125 ppm nitrogen using a 20-20-20 fertilizer. High pressure sodium supplemental lighting began the day after transplanting from 08:00 to 17:00 for the duration of the experiment. Plants were harvested at 34 days. Media and plant tissue were analyzed at harvest. Aerial plant growth was evaluated as described above. Root growth (r=4, n=3) was evaluated using scanned and digitized washed roots using WinRhizo PRO 2005 root analysis software (Arsenault, 1995) total root length (cm) and total root surface area (cm^2).

Experiments with Rinsed Media

Petunia Midnight Madness, plug size 512, were randomized and grown at the Washington State University research station in Mount Vernon, Washington in 72 cell inserts for standard 1020 flats, with twenty media treatments (t=20, r=5, n=1), 1) 70% peat moss, 30% P with 1.78 kg/m^3 DL and 0.89 kg/m^3 LF; 2)70% DF, 30% P with 0.89 kg/m^3 S^0; 3-7) 70% DF, 30% P with 0.89 kg/m^3 S^0, and 1.77, 2.36, 2.95, 3.54, or 4.13 kg/m^3 G; 8) 70% DF and 30% P with 0.89 kg/m^3 S^0 and 0.89 kg/m^3 LF; 9-12)70% DF and 30% P with 0.89 kg/m^3 S^0, 0.89 kg/m^3 LF and 1.77, 2.95 or 4.13 kg/m^3 G. Most of these treatments were duplicated using fiber rinsed in perforated buckets with 3X fiber volume of greenhouse tap water five days before mixing, except the 70% DF and 30% P with 0.89 kg/m^3 S^0, 0.89 kg/m^3 LF and 4.13 kg/m^3 G treatment. 500 ml pots were filled (5 reps/treatment) and watered in using greenhouse fertigation (125 ppm N) as needed. Pots were left to equilibrate for 96 h before planting. Substrate pH and EC_e were measured using distilled H_2O percolated through the medium on the day of planting and 2, 7, and 16 days afterward. Plants were harvested after 17 days. Aerial and root growth were evaluated as described above.

RESULTS AND DISCUSSION

DF samples contained significant amounts of plant nutrients with the most variability in Fe content. Mean pH was 8.4 and mean EC_e was 3.5 dS/m, both factors very different from peat moss. Na ion, as a percentage of EC_e ions ranged from a low of 3.9% to a high of 19.1%, with a mean of 9.4%. Differences in values from farm to farm probably are due to differences in inputs, technologies and modes of separation of the fiber (screw press and inclined screens) as well as exposure to rainfall (vertical movement of water soluble nutrients) and sampling point from the stored fiber.

Treatment of DF with S^0 was tested as a means of lowering the pH of the substrate and making Mn and Fe available to the plants. Supplementation at 0.89, and 1.78 kg/m^3 after 3 weeks incubation, lowered the pH to a range generally suited to plant growth (Fig. 1).

Analysis of 70% peat, 30% P and 70% DF, 30% P for porosity indicate significant similarities with some differences. The peat composite had 25.9% (vol.) readily available water (CC to 50cb) and the fiber composite, 23.4%. The peat composite had 10.5% (vol.) air space at container capacity (CC), while the fiber composite had 26.1%. The peat composite had a density at CC of 1.06 g/cm^3 and 0.76 g/cm^3 at 50 cb suction, while the fiber composite had a density of 0.99 g/cm^3 and 0.72 g/cm^3 (Figs. 2 and 3).

The first plant growth trial with unmodified DF as a major substrate of the growth medium produced plants that were chlorotic and unmarketable. Plants grown in peat moss medium had higher fresh weight, height, greenness, and number of flower buds. Plant tissue and medium analysis indicated that the most probable cause for the chlorosis was pH driven Mn deficiency, peat/P tissue Mn=242 ppm, DF/P tissue Mn=70 ppm.

In subsequent trials Mn and Fe in various forms was added to DF, including nutrient drenches and supplementation of the substrate. All treatments produced chlorotic plants. Plants grown in DF with either 204 ppm of $FeSO_4$ or 95 ppm of $MnSO_4$ were significantly less green than plants grown in peat moss with either 204 ppm of $FeSO_4$ or 95 ppm of $MnSO_4$, and the plants grown in peat had statistically higher fresh weight than those in DF.

Plants grown with S^0 added as an amendment to DF at a rate of 1.78 kg/m^3 S^0 had significantly better fresh weight, plant height, and greenness than lower, or no rate, of sulfur^0, or the standard limed peat moss media.

Subsequent investigation using digitalized root images indicated that while the aerial portions of the plants using S^0 were good, the root systems with that treatment were inadequate. Plants grown with 0.89 kg/m3 S^0 and 4.15 kg/m^3 G; or with 0.89 kg/m3 S^0, 4.15 kg/m^3 G, and 0.89 kg/m^3 LF had longer roots and greater surface area than plants grown with just S^0 or plants grown with standard limed peat moss medium and these differences were significant. Plants grown with both S^0 and G had significantly higher fresh weight at harvest than DF alone, DF with S^0, DF with S^0, G and LF, or plants grown on standard limed peat moss medium (Fig. 4). Plants grown in standard limed peat moss were the greenest of all treatments, followed by plants grown with just S^0.

Experiments with media rinsed with tap water starting on the day of planting indicated that substrate pH values were reduced in the rinsed treatments when compared to un-rinsed during all times. Substrate EC_e values were lower 0 days after planting (DAP) in the rinsed treatments when compared to un-rinsed, but were greater on average, in all DAP>0. There was no statistical difference in fresh weights among all un-rinsed treatments. There were significant differences in fresh weights between rinsed treatments, with 0.89 kg/m^3 S^0, 2.95 kg/m^3 G and 0.89 kg/m^3 LF treatment with the highest value. Fresh weight was higher in all un-rinsed DF treatment when compared to the similar rinsed treatment (Fig. 6).

CONCLUSIONS

The solid fraction (fiber) of the effluent of the anaerobic digestion of dairy manure by plug flow technology yields material that has appropriate physical properties; total porosity, air filled porosity at saturation, and water holding capacity to perform satisfactorily as a plant growth medium substrate. Unamended fiber, however, does not produce marketable plants. The use of S^0 to acidify the fiber produces plants with fresh weight and greenness equal to peat moss when used as a 1:1 replacement, but with inadequate root development. Adding gypsum along with S^0 as amendments to AD fiber produces aerial and root systems that are equal to peat moss when used as a 1:1 replacement as a substrate. The use of fiber for container media adds economic value enhancing the sustainability of dairy farming and additional values such as reduction in the release of greenhouse gases and water quality protection.

In these studies digested fiber (DF) has been shown to have physical properties similar to peat moss and that, although it has a high EC, most of that EC is due to plant nutrients. Plant growth trials indicate that amended DF can produce a substrate equal to peat moss for container plant media.

Some technologies described in this paper are protected under U.S. patent law.

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Figures

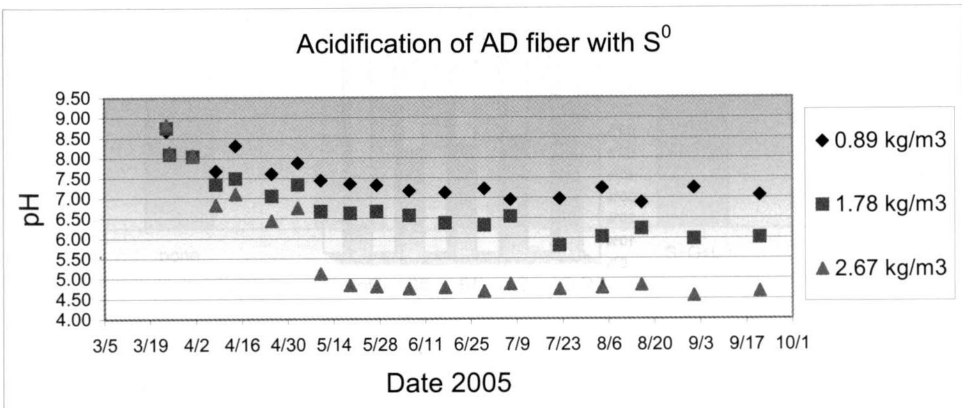

Fig. 1. Changes in anaerobically digested dairy fiber pH over time with varying rates of S^0.

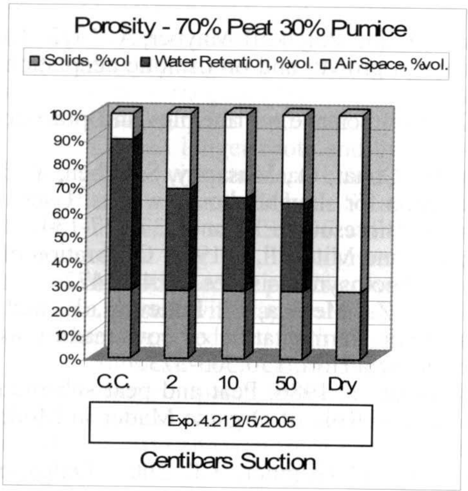

Fig. 2. Air and water filled porosity, horticultural peat moss and pumice.

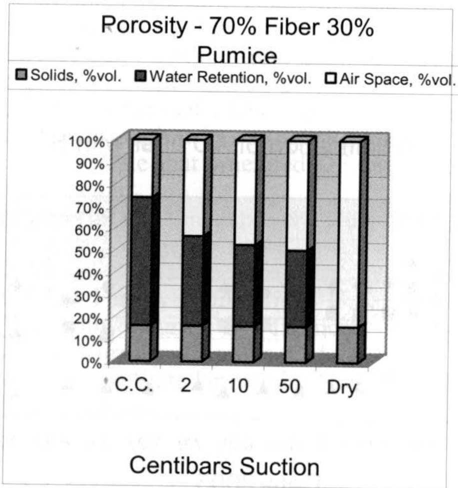

Fig. 3. Air and water filled porosity, dairy anaerobically digested fiber and pumice.

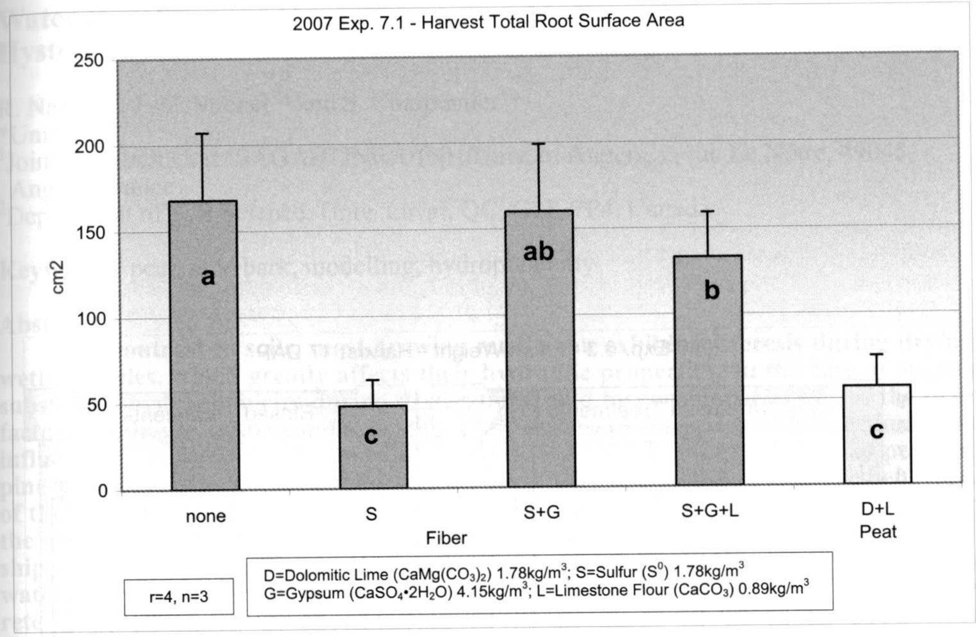

Fig. 4. Total root surface area (mean ± S.E.) *Petunia* grown in peat moss or anaerobically digested dairy fiber with S^0, gypsum ($CaSO_4$) and limestone flour ($CaCO_3$) treatments linked by the same letter do not differ significantly (P≤0.01).

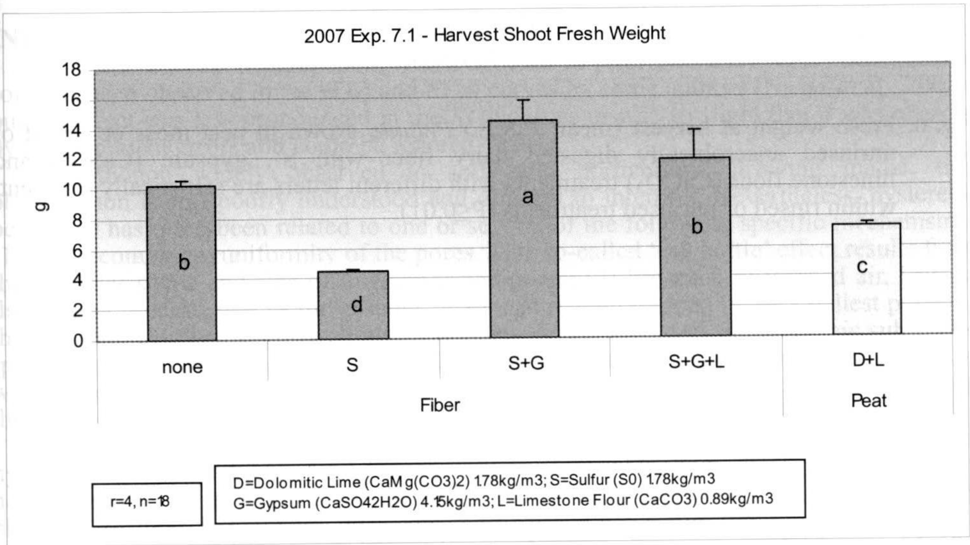

Fig. 5. Fresh weight at harvest (mean ± S.E.) *Petunia* grown in peat moss or anaerobically digested dairy fiber with S^0, gypsum ($CaSO_4$) and limestone flour ($CaCO_3$) treatments linked by the same letter do not differ significantly (P≤0.01).

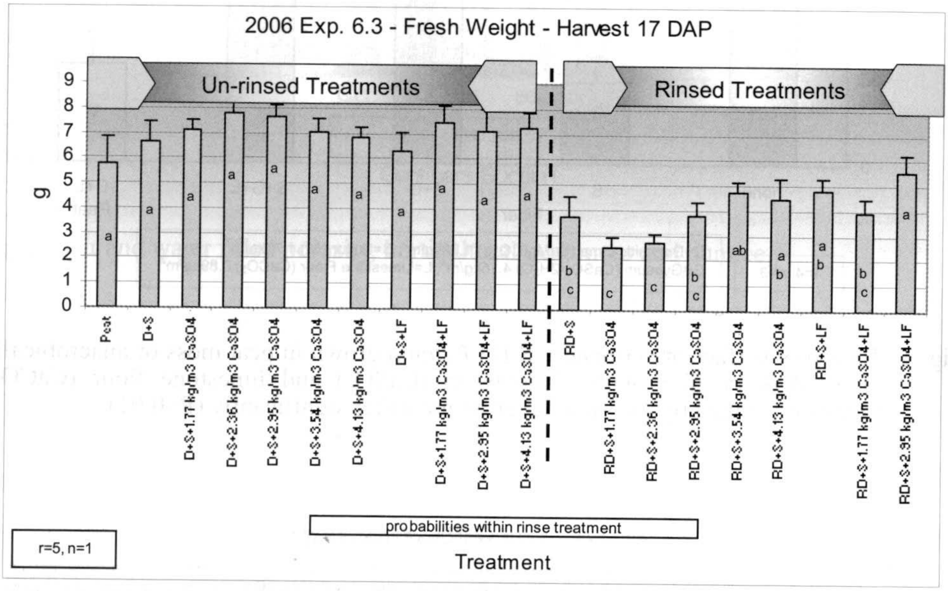

Fig. 6. Fresh weight at harvest (mean ± S.E.) *Petunia* grown in peat moss or rinsed or unrinsed anaerobically digested dairy fiber with S^0, gypsum ($CaSO_4$) and limestone flour ($CaCO_3$) treatments with different letters are statistically different, within rinsed or unrinsed treatments ($P \leq 0.01$).